If I had unlimited freedom in designing my courses I would simultaneously engage minds and hands by teaching from the lab. The very environment mandates active engagement where students must reflect on the what and why and synthesize knowledge from physics, engineering and statistics. The laboratory is as much a training ground for the specifics of our study as it is prime soil for the cultivation of robust problem solving and communication skills. It is the place where physical laws are witnessed and brought from the abstract to the familiar. However, given the practical limitations of teaching a large student body in the laboratory, one of my primary goals is to distill these experiences for presentation in the lecture hall. An effective arrangement that I like to employ is to first demonstrate experiments to generate discussion, followed by a presentation of analysis, and concluding with immediate opportunity for students to reciprocate through practice on variations of a theme.

For example, one of my favorite demonstrations for discussing oscillations is the blunt body suspended by springs. While mechanically simple, the complexities of aerodynamics presents an excellent pedagogical exericise in cutting through the details, and also offers a great subject for further discussions with eager students after class. I use this demonstration successively, first to introduce free, then damped, and ultimately, driven oscillations. The subject of driven and damped oscillations may often come as a shock to young students, as if free oscillations were not difficult enough! But these are precisely the concepts that are most important because of their broad application in physics and engineering. We conduct experiments by varying mass and spring tension, comparing our observations against the equations for a free oscillator. I ask for hypotheses on what will happen if we increase the damping. Some discussion of amplitude ensues, and then, by unfurling a few pieces of paper strapped to the blunt body, we increase the drag leaving the other quantities unchanged and find that the amplitude and frequency decrease. Why the frequency? By interacting with the air we have increased the inertia of the system. Only after reflecting on this new-found intuition do we proceed to include damping in an extended model of oscillations.

Two key observations from my teaching experiences are that students often struggle with the translation of problems into a mathematical form, and that learning often takes place through constructive imitation. The process of finding an effective mathematical representation of a physical system can be the most difficult step in an analysis, which is as true for the freshman student as it is for the seasoned physicist. By exposing our internal dialogue we present a template by which students first describe phenomena in their own words, only then moving on to graphical and subsequently mathematical representations. Like the learning of a sport or an instrument, we learn physics by observing and practicing, here the process of orderly reasoning that leads us from observation to conclusion. The goal of this is to elicit a dialogue with unprompted questions and freely advanced conjectures.

In a lecture on the topic of electric potential I once began with a discussion of the gel electrophoresis machine, a device commonly found in biology labs for genetic “fingerprinting” based on separation of DNA fragments. We first discussed the essential elements of the technique, stating what we knew of DNA - of phosphate groups and electronegativity, and then constructed a model of the system by considering the force on a negatively charged fragment in a uniform electric field. The conclusion that we are led to, however, is that all fragments move at the same rate, and hence, no separation should be possible! I let the students sit with this conundrum and move on to a discussion of voltage in electric circuits. At the close of the lecture we revisit the initial problem. We are forced to concede that our model of DNA migration must be flawed, and after some discussion a student suggests that perhaps we neglected friction. After some debate we are led to infer that a drag force proprotional to the square of the length of the DNA strand resolves the problem and is in good agreement with more detailed studies.

The ultimate goal of physics education is realized when we use knowledge founded on experience to extend our awareness to see things that were formerly invisible. By setting the stage with a tangible example, either through a demonstration or perhaps through a story of human interest such as asking “How were the ancient Romans able to move 300 ton obelisks from Egypt to Rome?”, we harness curiosity in search of general principles. Well-crafted experiments and demonstrations are powerful tools for initiating a conversation, and also do the subtle work of illustrating that science is not prescribed but constructed from careful measurement. The underlying mission of my teaching is to assist students by setting their curiosity in motion, enabling them to hone their potential for critical analysis, a widely transferable skill. We do this by steadily building our physical intuition on the bedrock of logic derived from observation and supported by a precise language that describes nature’s great patterns.